Optical Fibre Local Area Networks

Volume II

Part 1: LANs, MANs, and WANs

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ABSTRACT

Current limitations in the digital communications have sparked an interest in new ways to increase carrier frequencies and the actual information carrying bandwidth. The adoption of optical fibre technology as backbones and as core of the Internet has motivated similar interests within local area networks. Although the optical fibres would not replace completely the copper wired LAN, they will offer several desirable features that will make them attractive for general purposes. The fibre technology has grown rapidly since the discovery of the first low-loss fibres, as this has facilitated the development of faster and more efficient systems.

This chapter investigates how light has been an integral part of human communication systems, and its evolution into optical fibres has provided the medium to overcome some of the limitations of the traditional copper wired systems. The chapter examines the niche of optical communications at various levels of the LAN, and concludes by exploring the strengths and weakness of possible topologies to support future optical LAN. It provides an overview on how optical fibre can be and are used in Ethernet and FDDI infrastructures.

KEYWORDS

INTRODUCTION

The 1960's saw the advent of digital communications and electromagnetic waves as the primary means for information transmission. There is currently a constant demand for increased carrier frequency and larger bandwidth in order to accommodate the increasing volume of processed information (Kolimbiris, 2000). Conventional metallic or coaxial cable often suffer from attenuation due to spatial dispersion and heat, noise/interference and bandwidth constraints, as the energy of higher frequency signals are lost, usually as heat, in traversing the transmission medium where higher frequencies are attenuated as the distance of cable increases (Schneider, 1999). These limitations have sparked the need for new ways to increase the carrier frequencies and the information carrying-bandwidth. As a consequence, a great interest in fibre optics was triggered.

History

The use of light has been an integral part in the development of human communication methods, from early communication signals using light to current optical fibre systems that enable us to cover greater distances. Early systems generally had the constraints of sunlight availability, low information capacity or distance as in the communication system utilized by sailors who used lamplight to communicate with other ships or the shore in darkness.
Communication systems utilizing light can be traced back to 1880, when Alexander Graham Bell invented the photophone (Forrest, 1980). The Photophone, see figure 71.1, provided the means for Bell to transmit the first wireless telephone message. This was achieved by transmitting sound on a beam of light; the communication process was similar to that of the telephone except that this relied on light instead of electricity as the medium of transmission. The sender utilized sunlight as the light source, reflected onto a voice-modulated mirror to carry speech. At the receiver side, the modulated sunlight fell on a photo-conducting selenium cell that converted the message into electrical current, and a telephone receiver produced the sound.
As with many early prototype inventions it was not without its faults and therefore the significance of the Photophone was never realized until fibre optic cables had been developed.

Figure 71.1 about here

Today's optical fibres are flexible silica glass fibres although not to the extent of creating right angles without breaking. The flexibility is accomplished by carefully encasing the glass in plastic jackets for support while bending. Light is sent along the fibre and a light sensitive transistor detects the light pulses at the receiver. Optical fibre communication has several advantages (Comer, 2001). Optical fibres can carry more information (channels) over longer distances with fewer repeaters. They are much lighter than copper, therefore they occupy less volume in underground cabling ducts. They are immune against electrical interferences, and difficult to tap into without causing detection. For the same bandwidth, copper wired systems consume more power, even more for wire-pairs, to carry the signal than the optical fibres counter part. Therefore they keep the running cost of the system low. Despite all that, optical fibres have some disadvantages. Optical fibres are more expensive per meter than copper wires, although the sand is cheaper and abundant. However, the same fibre can carry far more transmissions than the copper, and fewer repeaters would be required for longer distance communications, keep the overall cost at a minimum. Other drawbacks involve the difficulties in joining fibres together and finding breaks. This requires special equipment and training.

Evolution

Originally the light sources were narrow bands of optic radiations in the form of a laser, which provided high capacity optical communication. The lasers were not guided like today's fibre optic cables and suffered similar problems encountered by Bell's photophone atmospheric interference. A clear line of sight was required between transmitter and receiver for successful transmission. However, the lasers produce an invisible beam that if in avertedly shone into the eye could cause damage.

This new development inspired developers to continue to research the technological constraints. The major limitation to overcome was the need to guide the light while providing the ability to actually bend it away from the straight line. Another drawback of this early optical technology was the opaqueness of the glass, which hindered research from possible longer distance communication (Palias, 2005).

The first low-loss fibres were introduced in 1970 (Palias, 2005); this accomplishment triggered the rapid development of fibre optic communication, leading to the rapid conversion of communication systems that previously relied on copper-wired technology to the faster more efficient fibre optic systems.

Today's technology is breaking communication barriers that were originally believed unfeasible. Initially the optical LAN's were only expected to connect buildings to create a larger LAN. The first optical Ethernet standard specified a single 2km optical repeater, but their spans were humbled by the maximum delay that could be allowed on an Ethernet LAN, while still detecting collision (IEC, 2005). The switched Ethernet LANs were further expanded by bridging the gap between two or more individual buildings. As optical links terminated at the switch ports, network performance was enhanced providing better network traffic control. To necessitate this process, the spanning-tree protocol (802.1D) was developed, which implemented path protection. Optical fibre technology could now enhance full-duplex transmission, which instantly doubled the bandwidth available. However, optical fibre LAN's were only constrained by the distance that the lasers (light emitting diodes) could reach.

In the next sections, we will examine different LANs expansions and connections based on optical communication. The following section, give an overview on the nature and properties of light when used in fibre-optic cables.

THE NATURE OF LIGHT

Light is often interpreted in different ways when dealing with different experiments. Sometimes it behaves like a wave and other times it behaves as a particle. In the context of this chapter we will look at light as being an electromagnetic wave with very high frequency and very short wavelength. The range of electromagnetic frequency is shown in figure 71.2. (ref ????)

Figure 71.2 about here

The light frequency spectrum can be divided into three general bands:

- Infrared: wavelength is too long and is invisible to human eye,
- Visible: wavelength is visible to human eye,
- Ultraviolet: wavelength is too short and is invisible to human eye.

For fibre optic communications, the carrier frequency range from about 200THz to 370THz, which falls within the infrared spectrum. It is more common to measure higher frequencies spectrum such as light in term of wavelengths. A wavelength is the distance between repeating units of a wave pattern. The length of the wave depends on the frequency as well as the velocity of light, $\lambda = C/f$, where λ is the wavelength (meters), C is the speed of light and f is the frequency (Hz).

Light Characteristics

The light travels in the free space with the speed of 3×10^8 m/s. However its velocity is reduced when it crosses substances with higher density (refraction index) than the free space, causing the light rays to be distorted (Tomasi, 2001). The speed of light in a given medium can be evaluated as $C_m = C/n$, where r is the refractive index of the medium and C is the speed of light in the free space.

Figure 71.3 about here

Reflection: The law of reflection specifies that, when a light ray is impinging upon a reflective surface at the angle of incident θ_1, it will be reflected from that surface with the same angle, $\theta_2 = \theta_1$, as shown in figure 71.3.

Refraction: When a light ray passes from a material of a given density to another material with higher density, it bends towards the norm. Conversely, if it travels to a material with lower density it bends away from the norm. Snell's law computes the angle of refraction for a given incident angle. The critical incident angle is defined as the angle that causes a 90° refracted ray from the norm, $\theta_1 = sin^{-1} (n_2/n_1)$. This will only occur when the incident ray travels from a higher refraction index to a lower refraction index media, $n_2<n_1$. Optical fibres operate on the principle of the total internal reflection of light where the light travels along the walls of the fibre, hits the wall at an angle larger than the critical angle and is reflected off the wall throughout the transmission.

Fibre Optics Cable

A fibre optic cable, as illustrated in figure 71.4 (Tanenbaum, 2005), consists of four parts:

- Core: Thin glass centre of the fibre where light travels in a zigzag mode using the cladding as the reflecting medium, with a total internal reflaction.
- Cladding: Outer optical material surrounding the core that reflects the light back into the core.
- Buffer coating: A protective layer, which prevents the fibre from damage and moisture.

- Jacket: A protective layer made of PVC or Teflon to protect one or a bundle of fibres against moisture, abrasion, crushing and so on.

Figure 71.4 about here

Classification of Optical Fibres

Optical fibres are classified into two categories, which are single-mode fibres and multimode fibres. The modes refer to the propagation characteristics of an electromagnetic wave as its travels through a particular type of fibre. In a single mode, rays of light travel in one direction, along the centre of the fibre. In multimode, rays of light travel in many directions, through a number of paths. The single mode fibre is usually used in long-distance transmission such as telephony and multi channel broadcast systems while the multimode fibre is best for short-distance transmission such as LAN systems and video surveillance (fibre-optics, 2005).

Single-Mode Fibre: The single-mode fibres (see Figure 71.5) have a smaller diameter (6-8µm) and lower density than that of a multimode fibre. As a result, the critical angle of the light beam is closer to 90° making the propagation of different light beams almost horizontal, thus lowering the signal distortion by minimising its dispersion (Forouzan, 2005). Usually, laser LEDs are employed as the source of light to cover distances reaching up to 50 km.

Figure 71.5 about here

Multimode Fibre: The multimode fibres have larger diameter (50-1000µm), which allows multiple beams from a light source to travel through the core in different paths, resulting in different arrival times at the end of the fibre. Multimode fibre is further divided into two categories: Step-index fibre and Graded-index fibre.

Step-index Fibre: In Step-index Fibre, the refraction indexes of the core and cladding are uniformly distributed over the whole substance. The core's index is higher than that of the cladding hence causing a total internal reflection when the light enters the core at an angle greater than the critical angle.

Figure 71.6 about here

In Figure 71.6, three rays of light waves travel in different direction down the core. The first travels straight down the center of the core, the second travels in a steep angle, which is reflected back and fourth, and the third are refracted into the cladding. It can be seen that the second ray travels a longer distance than the first one and hence both arrive at the destination at different times. This phenomenon is known as the modal dispersion, which causes a signal distortion at the receiving end, and therefore limits the transmission rate.

Graded-index Fibre: Graded-index fibre is manufactured in a way that the refractive index of the core gradually decreases from the centre of the core toward the cladding. This design speeds up the rays travelling away from the centre by reducing their velocities. It therefore permits most rays to arrive at the receiver within the same time. Figure 71.7 depicts the light rays following a serpentine path. It gradually bends back toward the centre by the continuously declining refractive index, hence reducing the pulse spreading. In reality, the optical source of light emits several different wavelengths that travel at different speeds. The graded index at the core, similarly to the single mode, causes a different pulse spreading called chromatic dispersion. Laser sources are monochromatic sources of light, when utilized they reduce the effect of chromatic dispersion.

Figure 71.7 about here

Losses in Fibre Optic Cables

There are several factors that complicate the transmission in optical fibres. They can be classified as linear and non-linear effects. The linear effects increase with the length of the fibre. It includes the attenuation and the dispersion. The attenuation is due to the progressive reduction in power of the light ray travelling through the fibre. Figure 71.8 shows the attenuation measured in the Silica for various wavelengths (Refi, 1999). The dispersion is due to the arrival of the wavelengths to the receiver at different times causing a spreading in the pulse and hence reducing the transmission rate. The delay differences among the wavelengths are caused in the multimode fibres, by the different paths, modal dispersion, and in the single mode fibres by the differences in the wavelengths speeds, chromatic and polarization-mode dispersions. The nonlinear effects on the other hand are problems caused by the optical signal power. For instance, scattering and four-wave mixing are such examples.

Figure 71.8 about here

Fibre Optic Communication System

Figure 71.9 about here

A general fibre optic system (see figure 71.9), similar to other communication infrastructures, has several components. The information source produces various types of information such as voice, data and video. The Encoder encodes the information into different formats indicated by the underlying technology and then passes them to the transmitter. The transmitter serves as a light source, which launches the light into the fibre-optic cable as well as a modulator that performs either analogue or digital modulation, for modulating light to represent the binary data that it receives from the source. The light source is either a Light Emitting Diode (LED) or a Laser Diode (LD). The emitted light is then coupled by a channel coupler that feeds power into the information channel before the light is transmitted into the fibre optic cable. The information channel is made up of either glass or plastic fibre optics, which guides the light waves from the transmitter to the relay nodes, and from the relay nodes to the receiver. The relay nodes may consist of optical amplifiers, repeaters, or switches (Transparent or opaque (Greenfield, 2002)) that route and regenerate the signals in long distance transmission, if required. The Receiver is either a PIN (p-type-intrinsic-n-type) diode or an APD (avalanche photodiode) where both senses light and converts it into an electrical current. However, the optical signal from the fibre-optic cable and the resulting electrical current will have suffered several losses. Consequently, the photodiode circuitry must be followed by one or more amplification stages. There might even be filters and equalizers to shape and improve the information-bearing electrical signal. The decoding part turns the modulated signal into binary form and delivers it to the information receiver.

OPTICAL LANS

The emergence of new high bandwidth-intensive multimedia applications makes effective bandwidth allocation in LANs an increasingly important issue. Optical fibre technology provides the bandwidth necessary to support such applications. Optical Local Area Networks (Optical LANs) transmit data to stations within a limited region that are in the same geographical space, for example in the same building. Shorter transmission distances decrease the error rates, for example when transmitting to stations within the same room, the error rates are approximately 10^{-12} (Palais, 2005). The signal within the optical LAN is split to accommodate all stations within the network; each station will receive $1/n^{th}$ power of the signal.

<u>Single-Hop LANs</u>

Figure 71.10 about here

In the bus topology (see figure 71.10) the signal transmitted by each station is coupled into the bus, and splits to supply each receiver. A disadvantage to this topology is the power asymmetries. The signal reaching terminal, N, from terminal $N - 1$, is stronger than the signal from the first terminal (Chapman, 1989).

Figure 71.11 about here

LANs adopting a star topology uses the power more efficiently, and facilitates a shared medium optical LAN. The star coupler combines the signals from the transmitters and splits it into n signals sent to each receiver (Walrand & Varaiya, 2000). Perhaps, the constraint of this topology is the size and the number of ports of the coupler. This is a serious issue with network scalability. Fortunately, cascading couplers on specific wavelengths, as shown in figure 71.12 permit the network to expand further and covers a larger number of distributed stations.

An interconnection between two stations lasting for the length of a data packet is set up on the control channel, by the transmitting station that informs the receiving user where to tune in to receive the data packet. If the optical star is operated with a single wavelength then it operates at the same level as an Ethernet. All the stations hear all the traffic and pick off only those addressed to them.

Figure 71.12 about here

In both topologies the signal from all the transmitters will broadcast to all the receivers. Each station transmits on one wavelength but receives all the wavelengths, therefore requiring a tuneable transmitter or receiver to select the desired wavelength. The introduction of a control channel where any stations wishing to communicate are required to request resources provides a more powerful, although complex, network configuration.

Multihop LANs

Single hop LANs do not scale easily and require tuneable receivers whereas the multihop configuration utilises a fixed receiver and transmitter wavelength and are scalable. The 8-station shuffle network configures each station to receive and transmit two wavelengths, the assumption is that the wavelength conversion is possible at each station and can be used simultaneously on two different hops.

OPTICAL ETHERNET

Brief review on the Ethernet

Ethernet developed by Xerox and adopted as the LAN standard by the IEEE 802.3 committee has dominated the LAN and became the starting and ending points of the Internet.

The classical Ethernet, operating on a speed of 10Mbps, works on a bus topology under the control of the CSMA/CD protocol located in the MAC sub-layer. Stations are tapped to the coaxial cable with transceivers. At both ends of the bus are terminators that remove the signal preventing it from reflecting back and hence interfering with the transmitting station. The bus spans a maximum distance of 200m or 500m depending on cable type. CheaperNet or 10BASE2 expands to 200m, and ThickerNet or 10BASE5 expends to 500m, at which point the signal degrades to a level were repeaters are required to boost the power into the signal. Stations asynchronously compete for the line – cable – to transmit their frames. The contention mechanism is based on the Carrier Sense Multiple Access with Collision Detection, CSMA/CD. When a station receives a packet to transmit, the circuitry of the Network Card (NIC) senses the line. If the line is busy – a transmission is in progress with bit transitions occurring in the medium – the station waits until it becomes idle. When the line is idle, the station transmits the frame. There are several variants to this protocol regarding the behaviour of the sending station after the line is detected idle. In the Ethernet, the station immediately transmits when the line is available. It may happen that two or more stations attempt a transmission at the same time. If this is the case, a collision occurs. The protocol has the capability to detect collisions and force the stations involved in the collision to back off for random times, before attempting another transmission again. The collision detection capability is a function of the bus length, ***D***, and the Ethernet frame length, ***L,*** at the NIC transmission rate of ***R*** Mbps, and the speed of the wave in the medium ($C_m = C/r$)

$$\frac{L}{R} \geq \frac{2Dr}{C} + \varepsilon \qquad (1)$$

where ***C*** is the speed of light, ***r*** is the refraction index of the core, and **ε** in μsec is the latency associated with all repeaters or hubs and stations along the segments. $\mathbf{L_{min}/R}$ refers to the collision domain, which defines the minimum frame size to be transmitted to detect a collision. Any transmission taking place within this domain will indisputably result in a collision. The minimum frame size for a 2500m bus, or five ThickNet segments, with four repeaters at the transmission speed of 10Mbps is about 512 bits (Stallings 2002). Equation 1 is valid for a fibre connections; for a copper connections the speed of the signal in the electrical material is approximately 2/3 the speed of light. In the next sections, we will show how equation 1 entails constraints on high speed and fibre optic Ethernets.

Bus, Star, mesh and hierarchical Topologies

Since the bus configuration, the Ethernet has adopted various interconnections, including the star topologies with the hub or the switch at the centre connected to all the stations via a RJ-45 connector. To scale and expand the LAN further, multiple switches with possibly different speeds and level of routing – layer 3 switching – are interconnected in mesh configurations. Such topologies have to be carefully planned, possibly adopting VLAN, to achieve the maximum bandwidth and manageability. Hubs or switches can be connected in tree configuration forming a deep hierarchy of switches or hubs with stations located at the leaves. Although electrical cables link most Ethernet LANs, the situation is most likely to change in the immediate future. Fibres are electrically noiseless, less dense than wires therefore easy to put in building conduit, highly secure and support much higher speeds and distances than copper.

10BASE-F: The dominating technology based on 10BASE is the twisted-pair copper. However, several fibre standards – 10BASE-FL (Fibre Link), 10BASE-FB (Fibre Backbone), 10BASE-FP (Fibre Passive), and FOIRL (Fibre Inter-Repeater Link), have been developed to target different market needs. Perhaps, the success of the twisted-pair, at this time, was due to the unused bandwidth of the fibre, as the signalling rate of 10Mbps occupies a smaller fraction of it. The other reason would be the cost of the opto-electronic equipment that converts between light and electricity.

Fibre connections require two separate lines one for transmission and the other for reception. For link integrity, an active idle signal of 1MHz (FL) or 2.5MHz (FB), depending on the standard, is monitored. If the Medium Attachment Unit (MAU) fails to detect this signal, it declares the link as failed and prevents the station or the repeater from transmitting. Nowadays, many vendors optionally supply a link light on the MAU to give you a visual indication of the link integrity status. Fibres for the 10BASE-F rely on multimode transmissions with core and cladding diameters of 62.5μm and 125μm respectively (Kadambi, Crawford & Kalkunte, 1998). Although vendors have produced many methods to connect the fibre to the MAU, the Bayonet Fibre Optical connector, BFOC, and the ST are the most commonly used (Shah, 1993).

In general 10BASE-F segments can span up to 2Km if used exclusively with 10BASE-FL and up to 1Km if used with the FOIRL. 10BASE-FB is mainly used to connect additional hubs or repeaters. As it has the ability, in its design as oppose to FL, to signal remote faults between the two hubs. The maximum distance that this fibre extends to is about 2km, although, when used with other standards, it would span up to 1km. Finally, 10BASE-FP implements a rather different topology. The stations are connected to a passive hub forming a star topology, similar to figure 71.11. The passive hub is convenient in places where electrical powers are hazardous and impractical in some areas. The hub floods the light pulses on all its ports without converting them to electrical signals. Hence, if multiple light pulses occur simultaneously at the hub, the signals interfere causing a collision.

Figure 71.13 depicts a possible mixed topology with all the optical connections, following the IEEE restriction on the fibre length. It must be noted, according to equation 1, that the collision domain, rather than the attenuation constraints limits the length of the fibre.

Figure 71.13 about here

<u>100BASE-F</u>: To satisfy applications demanding higher bandwidth, Ethernet has been driven into two complementary directions. The switched Ethernet, where the central hub is replaced by a switch, and therefore, providing full-duplex connection without a collision, or faster Ethernet, where the clock or the speed of the NIC is increased by a factor of 10, yielding 100Mbps transmission. In the former, restrictions on the length of the fibre are only imposed by the attenuation factors, and therefore larger topologies can be supported. In general, it is used in long-haul communications such as establishing connections between buildings. On the latter, the increase of speed to 100Mbps, required a decrease of the fibre length by a factor of 10, refer to equation 1. Hence, 100BASE-FX, the only standard in this class, has a much smaller geographical limit, a maximum length of 400m. It is noted that with a mixed topology, using class I hubs, the maximum span of the fibre would be 130 to 160 m (Kadambi et al., 1998). 100BASE-FX uses two strands of graded-index multimode over a pair of fibres, 50/100μm, or 62.5/125μm.

The signalling speed in 10BASE is 20MHz with Manchester encoding, however, with 100BASE the same encoding technique would have required a clock of 200MHz. Instead, 100BASE-FX, similarly to 100BASE-TX, adopts the 4B/5B-encoding scheme, as shown in the simplified diagram in Figure 71.14. This code has already been deployed by FDDI, where four data nibbles are converted into 5 binary codes, chosen out of the 32 codes.

Figure 71.14 about here

Two classes of hubs have been designed to permit interconnections with 100BASE media types.

Class I hub supports all 100BASE media types. This flexibility comes at the price of high latency that is induced when the hub converts from one code to another, and therefore reduces the length of the cable or the fibre. For instance, 100BASE-TX and 100BASE-FX use 4B/5B-coding scheme, 100BASE-T2 uses PAM 5X5 codes, and 100BASE-T4 uses 8B/6T codes. When 100BASE-FX is deployed with a class I hub within the mixed topology of 100BASE-T2 and 100BASE-T4, the maximum length of the fibre, limited by the collision domain, refer to equation 1, would be 130m. Whereas, when the class I hub connect only 100BASE-TX and/ or 100BASE-FX, the length of the fibre can be extended to 160m.

Class II hubs are a two hub topology with 5m separation between the hubs. It supports only 100BASE-TX and 100BASE-FX, therefore eliminating the code conversion process. This reduction gains extra spanning, and allows the fibre to extend up to 200m, from the station to the hub. Figure 71.15 illustrates a mixed topology of 100BASE-TX and 100BASE-FX with class I hub and class II hub, and the switches operating on full and half duplex. The exact length of the cable for half-duplex must satisfy the inequality 1. The delay in the hubs and the stations with a margin of 32bits is taken into consideration. Obviously, manufacturers design hubs, and switches with different delays; these have to be taken into consideration when connecting optical LANs.

Figure 71.15 about here

1000BASE-F: Increasing the speed to 1000Mbps will result in a decrease of 100 times in the length of the segment. Theoretically, the length of the segment in a half-duplex connection would be 20m (Tanenbaum, 2004). This limitation is unacceptable for such a high transmission rate technology, especially when used with fibre optics. Several design mechanisms have been deployed to overcome these limitations, while maintaining the compatibility with predecessors, 10BASE and 100BASE standards. The simplest approach would be to abolish the half duplex completely and connect stations to switches, thus removing the collision domain restrictions. This approach is becoming more popular, as the prices of the switches are dropping. Furthermore, an adoption of fibre solutions with cheaper switches would be a more realistic and popular solution to the future LANs and desktops. The efforts of the IEEE 802.3z task force went to the proposal of a carrier extension. This scheme involves changing the collision domain (time slot) from 512bits to 512Bytes (4096) to maintain a segment of 8 times longer than that suggested by equation 1. The approach requires that frames of size less than 512bytes have to be padded by extra bytes, called an extension. Certainly, these extra overheads would reduce the efficiency of the Gig Ethernet to 12% (Haddock, 1996). Several approaches have been proposed to increase the efficiency to 72% (Molle 1996) at least to match the 100BASE efficiency. Mainly, the frame bursting which involves sending several frames within a burst limits (65536bits) has been approved by the IEEE 802.3z task force (Molle et al, 1997), (Haddock, 1996), (Kalkunte, 1996). 1000BASE relies on Fibre Channel (FC) technology, connection for high-speed devices, at the physical layer. The physical Coding Sub-layer of the physical layer, that implements Manchester encoding in 10BASE and 4B/5B encoding in 100BASE-TX, supports IBM 8B/10B code, which has an effective performance (Widmer, 1983). A very simple implementation of the code is to partition it into 5B/6B and 3B/4B subordinate coders.

Furthermore, the physical medium dependent sub-layer relies entirely on FC0, Fibre Channel layer 0, dealing with connectors, and optical interfaces.

1000BASE supports two different media types: namely 1000BASE-SX (Short wavelength Laser) and 1000BASE-LX (Long wavelength Laser). 1000BASE-SX uses short wavelength laser in the region of 850nm over a multimode fibre 50/62.5μm. 1000Base-LX uses long wavelength laser 1300nm over multimode fibre 50/62.5μm and single-mode fibre 2/10μm. The multimode covers a distance from 220-550m, whereas the single mode spans over distances of 5Km. Figure 71.16 depicts a possible network topology of 1000BASE-SX and 1000BASE-LX. As embedded in equation 1, the distance of the cabling is a function of the components delay and the speed of the light in the core. The exact distances will be deduced from the manufacturing specifications. The configuration in Figure 71.16 relies on the default values, providing the time slot 4096bits of 1000BASE is obeyed.

Figure 71.16 about here

<u>10GBASE-F</u>: Although this technology may not be deployed now for LANs, except for parallel systems and high-speed servers, it is more attractive and appealing in the market of carrier networks. The speed of 10Gig Ethernet is about SONET, SDH, and OTN. It is worth mentioning that the success of Ethernet is its simplicity and low cost. These features would be carried over to the WAN, where the 10Gig Ethernet will play a major role. Ethernet equipments would be able to connect network premises to network carriers at no additional cost, induced by the use of SONET or SDH interfaces. It is expected that 10Gig Ethernet will interconnect LANs, MANs and WANs.

From the design point of view, refer to equation 1, it is apparent that an increase of 10000 times in the speed should be followed by a reduction of 10000 times in the segment length, yielding a figure around 0.2m. This is impractical and unacceptable even for home networks. The design of 10Gig Ethernet and possibly 100Gig Ethernet reply on full-duplex operation, with connections to switches (e.g. layer-3 switching) or routers. The optical fibre segments would only be limited by the attenuation factors. Currently, the technology permits 10Gig Ethernet single mode optical fibres to span a distance up to 40km.

Although 10Gig Ethernet is intended to be entirely supported by optical fibres, IEEE802.3 committee has proposed two standards for 10Gig Ethernet over cable. 10GBASE-CX4 operates over limited distances from 15 to 30m over 4-pair of twinax cable each running at the data rate of 3.125Gbps. With the 8B/10B encoding, this standard gives the required 10Gbps. The goal of this standard is to support low cost inter-rack solutions. 10GBASE-T operates at full duplex with cat 6 (class E) and cat 7 (class F) for up to 100m with four twisted-pair copper. Cat 7 is adequately specified for this bandwidth; however, cat 6 would have to have its performance characterised beyond 250MHz up to 450MHz. 10BASE-T achieves the 10Gig speed by deploying 10-level PAM signalling with 3-bit per level, over four lanes of 833Mbps, yielding an aggregate transmission rate of 10Gbps. This technology offers cheaper installation over fibres. The market would target data centre and horizontal enterprise networks.

Although 10GBASE is similar in every way to its predecessors to maintain compatibility with the reconciliation sub-layer, it differs in the physical layer, as it is meant for a different purpose. The encoding techniques utilized in the PCS, physical coding sub-layer, are the 8B/10B, similar to 1000BASE, and the 64B/66B. IEEE 802.3 task force have used the suffix 'X' to refer to the 8B/10B-encoding scheme. On the other hand, the physical layer implements different wavelengths and fibre modes. For instance, the suffix 'S' refers to 850nm wavelength with a serial transceiver on two multimode fibres. The suffix 'L' refers to 1310nm long wavelength with a serial transceiver on two single mode fibres. The suffix 'L4' refers to 1310nm long wave with four wave division multiplexing, WDM, on a two multimode or two single mode fibres. Finally, the suffix 'E' refers to 1550nm extra long wavelength with a serial transceiver on a two single mode fibres. These standards can be combined to create several media types for the optical 10GBASE Ethernet.

10GBASE-LX4 or simply <u>10GBASE-X</u> utilises 8B/10B-encoding scheme at the PCS sub-layer, with four WDM and a long wavelength, 1310nm, over distances of 300m (multimode fibres) to 10Km (single mode fibres). This would be a possible candidate for MANs, when the entire infrastructure is Ethernet-based to avoid any protocols or framing conversions.

10GBASE- SR, -LR and –ER or simply <u>10GBASE-R</u> uses 64B/66B encoding scheme. They deploy short wavelength, 850nm, on multimode fibres, long wavelength, 1310nm, on single mode fibre, and extra long wavelength, 1550nm, on a single mode fibres over distances 65m, 10km and 40km respectively. This technology is intended for LANs and WANs where the infrastructure is all Ethernet-based. Finally, 10GBASE-SW, -LW and –EW or simply 10GBASE-W uses the same technology as 10GBASE-R with the exception of an additional sub-layer, called WIS, WAN Interface Sub-layer. This sub-layer permits 10GBASE-W to connect to SONET, which dominates the WAN market today. Most vendors believe that 10GBASE-W and the future versions would dominate the carrier networks rending the entire public network a large Ethernet LAN. Figure 71.17 depicts a possible connection with the mixed interconnections of all the 10GBASE classes, while maintaining, the segments length restrictions. In full duplex, the length of the segment is restricted by the factor MHz*Km. For instance, LX4 spans a distance of 300m at the rate of 500MHz*km.

Figure 71.17 about here

OPTICAL RING

Fibre Distributed Data Interface, FDDI, has been the LAN standard operating at the speed of 100Mbps long before the 100BASE Ethernet was designed (Ross 1986, 1989). It specifies a transmission over dual ring optical fibre primary and secondary rings, using token passing access protocol. Both multimode and single modes are deployed to span longer distances. Similar to 100BASE Ethernet, FDDI relies on the 4B/5B encoding/decoding technique to provide transmissions with synchronisation and clocking. Although, FDDI, similarly to Copper Distributed Data Interface (CDDI), can be utilised for LAN to attach workstations and servers, its speed made it a favourable candidate for backbone networks, where stations could be switches or bridges. Figure 71.18 shows FDDI wiring and connections to different stations using patch panels and concentrators. Single stations (SAS), are attached to the ring concentrator and mainly inject and remove traffic from the primary ring. Dual stations (DAS), are connected to the secondary and primary rings. The ring has some degree of fault tolerance. If the DAS or the optical fibre fails, the ring wraps itself by connecting the secondary to the primary rings, hence isolating the faulty cable or station. Further optical bypass (internal mirrors) can be used to reflect the light and hence bypass faulty stations, as shown in the DAS of Figure 71.18. With critical devices such as routers and servers, dual homing is used to provide additional redundancy and help maintain the ring operation by attaching critical devices to many concentrators.

Figure 71.18 about here

FDDI Standards for Ring Management: All FDDI standards reside on physical and data link layer of the OSI model. Physical Medium Dependent (PMD) and Physical Layer Protocol (PHY) fit into the Physical layer, Media Access Control (MAC) and Logical Link Control (LLC) resides on the Data Link Layer while Station Management (STM) fits into both layers.

Station Management (SMT): FDDI Station Management (SMT) is the layer, which maintains the overall ring operation including error reporting and fault isolation. SMT is also responsible for initialization, insertion and deletion of nodes in the ring. Information of each node is stored the Management Information Base (MIB). A MIB includes the things like the unique station identifier, the SMT version, the station configuration information, the available paths, and the number of MACs in the station, the current port configuration, and the status report frames that are queued. Every node in the ring communicates with others by exchanging information using the SMT frames. Listed below are different types of frames with their unique functionality:

Connection Management (CMT) specifies the physical connection status between two neighboring stations on whether they are OFF, ON, ACTIVE or CONNECT.

Configuration Management (CFM) manages information of MAC connection and defines PHY and MAC parts in a station.

SMT Entity Coordination Management (ECM) manages the operation of CFM and PCM by controlling the trace and optical bypass relays.

Ring Management (RMT) informs the LLC on whether the MAC layer is ready to detect duplicate addresses and stuck beacons in the link.

Neighbour Information Frames (NIF) provides information of a node to its neighbouring node from the **Management Information Base (MIB)** every 2 to 30 seconds while detecting duplicated MAC address in a ring.

Status Information Frames (SIF) provides configuration and operation information to the neighbouring nodes from the **MIB**.

Parameter Management Frames (PMF) provides remote access capabilities to a station attribute. The PMF-get is use to read the value of any parameters of a remote station while PMF-write writes value into a remote station.

Status Report Frames (SRF) are sent via SRF multicast address whenever there is a change in the ring configuration.

To implement the access to the ring, FDDI deploys the same principle as the token ring. The management station plays an important role to maintain a fair and efficient access to the ring. Both synchronous and asynchronous traffics can be supported at the same time (Joshi 1986). In particular, FDDI-II has optimal features in the MAC layer to provide QoS for delay-sensitive applications.

In general, FDDI uses timed token rotation protocol, which presets a defined value called target token rotation time (TTRT). The manager station adjusts this counter and broadcasts it to all stations sharing the ring. The counter (TTRT) plays an important role in the performance of the ring. Upon receipt of the token, a station transmits queued frames up to the time hold timer (THT), then passes the token to the next station in turn. In this case, each station based on the actual traffic dynamically calculates the value of THT, which is utilised to maintain a fair access to the ring by all the stations, and hence defines the performance of the ring.

As shown in figure 71.19, the maximum throughput of the ring increases with the target token rotation protocol. However, the maximum access delay also increases, refer to figure 71.20. A minimum value for the TTRT (4ms) can offer a good ring performance. In general, the maximum standard value for the TTRT can go as high as 165ms, producing a very high access delay.

FIBRE CHANNEL

Fibre Channels (FC) are developed to support networks for storage, such Storage Area Networks, SANs. This section describes the briefly the FC technology. FC networks use 30bytes network address similar to the MAC addresses and 8bytes World-Wide Name

(WWN) to ensure the uniqueness of every device attached to them. On the other side, FC networks face a massive competition with Gig Ethernet technology and an enduring challenge for market acceptance.

Fibre Channels define their own standard. FC-0 layer corresponding to the physical layer of ISO focuses on the transport of bits streams across the medium. Although twin axial copper can be supported, the preferred medium is the optical fibres. For a distance ranging from 175m to 500m, multimode fibres with 62.5μm/125μm and 50.0μm/125μm are implemented. Greater distances such as 10km could be reached with single modes of 9.0μm/125μm core/cladding. Special connectors, GBIC (Giga Bits Interface Connector) are used to join the fibres to the HBA (Host Bus Adaptors), into the controller card. FC-1 layer similarly to the PCS sub-layer in the Ethernet converts bit data with the 8B/10B-coding scheme to overcome the DC components and the lack of synchronisation, and also embeds the clock signalling within the data (Widmer 1983). FC-2 layer deals with framing, flow control and class of services. Three service classes are supported by FC. Class 1 establishes` reliable connection-oriented communication between a server and a disk array for instance. This class requires a switch to establish a dedicated connection with guaranteed bandwidth between the two devices. Class 2, rarely used, is a reliable connectionless-oriented communication with no dedicated bandwidth. Finally, class 3 offers an unreliable connectionless-oriented communication between devices much like UDP/IP in the Internet. Encryptions and authentications are handled in the common services at the layer FC-3. Finally, FC-4 layer is the upper layer protocol, similar to the transport or TCP, and UDP layers. It supports direct storage device read/write through a Virtual Interface (VI), IP tunnelling and the fibre channel protocol, FCP. The objectives of the development of this layer is to offer operating systems seamless access to the storage devices should they be attached to SCSI interfaces or to SANs (Clark 2002). A possible FC interconnection is shown in figure 71.21.

Figure 71.21 about here

OPTICAL INTERNET AND MPLS

The realisation of an Optical Internet depends on the synthesis and standardisation of protocols that work in a multi-vendor environment. “*The number of carriers deploying new MPLS-based metro Ethernet equipment doubled between 2005 and 2006, from 42% to 84%*” (Campbell, 2006).

Research in the IP community integrated the IP protocol into connection-oriented technology, with the aim to improve QoS providing a virtual circuit to support end-to-end packet transfer. Using a virtual path promotes efficient allocation of network resources via statistical multiplexing, enabling QoS assurances to be made as opposed to the ‘best effort’ service provided by IP.

Figure 71.22 about here

MultiProtocol Label Switching (MPLS) (Figure 71.22) is a suite of standard routing and signalling protocols that supports a variable length stack of four-octet labels at the beginning of an IP packet. It is the first of these labels that help the Label Switching Router (LSR), utilizing the label-forwarding table, to determine the packet output port or the label-switch path (LSP). Connections established using MPLS build on current protocols such as OSPF and Intermediate System to Intermediate System (IS-IS) – to exchange link-state topology (Basak & Siket, 2000). MPLS can provide rapid restoration of packets in an IP network at the point of failure by rerouting to another LSP.

The label switching and packet forwarding processes are completely decoupled from how the LSP's are created and destroyed. The MPLS paradigm is much simpler than traditional IP routing allowing much larger numbers of packets per second to be processed (Ramaswami & Sivarajan, 2002). The major benefit of decoupling these functions is any optimization of packet forwarding will be autonomous of label-switch, which is not the case in IP routers. There are synergies between MPLS, LSR and Optical Cross-Connects (OXCs) and the MPLS LSP and Optical Channel Trail. Similar to MPLS, OXCs need routing protocols such as OSPF and IS-IS to establish optical resource availability for path computation. Also Similar signalling protocols such as RSVP and LDP are used to configure OXCs to establish optical channel trails. The Internet Engineering Task Force (IEFT) has proposed MPLS as the model to adapt for optical devices. OXCs are emerging as the fundamental building block of a seamless optical transport network.

SUMMARY

The demand for greater bandwidths is accelerating the distribution of fibre optic communication systems. Fibre optic cables have been used successfully in long-distance communication; with over 8% of the world's telecommunication systems are now utilizing fibre optic cables (Bellis, Internet Source).

Telecommunication and Cable companies have merged resources to distribute their services via fibre optic cable to the home. This has lead to standards being defined these incorporate five key criteria (Sprint Corporation, 1999).

1. Ability to carry multiple protocols
2. Maintain architectural flexibility
3. Provide good diagnostic capabilities for signal quality and fault management
4. Transparent data transport protocols
5. Compatibility with data transfer methodologies

Although the increased performance and greater bandwidth has been attractive for local area networks (LAN's), economic considerations have limited its development in this area, previously. But with today's demands forever increasing bandwidth coupled with the diminishing cost, fibre optic LAN's are replacing twisted pair or coaxial cable networks and are now the infrastructure of choice. As fibre optic cables are implemented in areas that have an electrically noisy environment or systems that carry sensitive data. There are also minimal issues with building regulations when implementing an optical fibre network as opposed to an electric cabled one

Reducing the distance of the optical fibre cable to support higher speeds than copper cable can achieve, for example a 30 meter copper cable can support a Gigabit bandwidth. The proposed 10 Gigabit Ethernet will reduce the distance of the cable still further. This is the area where optical fibre technology will come into its own.

Optical communication has migrated from the WAN and MAN to the LAN as we have identified in this chapter across many technologies Ethernet, Ring and Fibre Channels. Such a leap might reach the internal architectures of the servers and the PCs. Instead of electricity, the stations will operate entirely by optics/photons hence breaking the barriers of speed and bandwidth limitations imposed by the electrons. Furthermore, optical wireless is an interesting domain that will be well accepted by the ad hoc network infrastructure, especially in large-scale ad hoc networks (Adda, 2005), (Owen, 2005).

GLOSSARY

1000BASE-LX	A fibre optic gigabit Ethernet standard, using a long wavelength laser. Can work over a distance of up to 2 km over 9 µm single-mode fibre.
1000BASE-SX	A fiber optic gigabit Ethernet standard, that operates over multi-mode fiber using a 0.85 micrometre near infrared light wavelength. The specification allows for a maximum distance between endpoints of 220 m over 62.5/125 µm fibre, although can usually work over significantly longer distances.
100BASE-FX	The IEEE Fast Ethernet standard for 100 Mbps Ethernet over fiber optic cabling. It uses two strands of multi-mode optical fiber for receive and transmit.
100BASE-T2	100Mbps ethernet over Category 3 cabling. Supports full-duplex, and uses only two pairs. It is functionally equivalent to 100BASE-TX
100BASE-T4	The IEEE Fast Ethernet standard for 100 Mbps Ethernet over category 3 UTP/STP. The IEEE Fast Ethernet standard for 100 Mbps Ethernet over category 3 UTP/STP
100BASE-TX	The IEEE Fast Ethernet standard for 100 Mbps Ethernet over category 5 UTP/STP.
10BASE-FL	The implementation of the 802.3 standard designed to operate over fibre optic cable at 10 Mbps.
10BASE-FP	A passive star network that required no repeater.
Bandwidth	The data-carrying capacity of a transmission medium measured in bits per second (bps) or in cycles per second or Hertz (Hz).
Bridge	A networking device that connects local or wide area networks using the same or different data-link layer,
CDDI	Copper Distributed Data Interface. Copper cable based implementation of FDDI.
CSMA/CD	Carrier-Sense Multiple Access with Collision Detection. The network-access method used by Ethernet networks.

DAS	DAS is storage that is directly connected to a server by connectivity media such as parallel SCSI cables.
Ethernet	A 10-megabit per second (Mbps) baseband-type network that uses the contention-based CSMA/CD media access method. Invented by Robert Metcalfe (*Now 3COM*) at **Xerox'**s Palo Alto Research Centre in the mid-1970s.
FDDI	Fibre Distributed Data Interface is a media access (transmission) control-level protocol with token-ring architecture, a communication bandwidth of 100 Mbps and supported on a fibre network medium.
FOIRL	Fiber Optic Inter Repeater Link - An early implementation of a subset of the 802.3 10Base-FL standard designed to connect fiber optic repeaters at 10 Mbps.
FSPF	Fabric Shortest Path First is a routing protocol used in Fibre Channel networks. It calculates the best path between switches, establishes routes across the fabric and calculates alternate routes in event of a failure or topology change.
GBIC	Gigabit Interface Converter; a Fibre Channel optical or copper transceiver that is easily swapped to offer a flexible choice of copper or fiber optic media
HBA	Host Bus Adapter, that plugs into a host enabling the host to communicate with a SCSI device.
IEFT	The Internet Engineering Task Force (IETF) is charged with developing and promoting Internet standards
IS-IS	Intermediate System-Intermediate System is an International Organization for Standardization (ISO) dynamic routing specification.
LAN	Local Area Network is a computer network covering a local area, like a home, office or small group of buildings.
LSP	Label Switched Paths are often also referred to as tunnels. LSPs are used to transport data, such as IP packets, across an MPLS network.
LSR	A node that resides inside the MPLS domain boundary and does no IP forwarding.
MAN	Metropolitan Area Network. A data network designed for a town or city. MANs are larger than LANs, but smaller than WANs

MAU	Media Access Unit, an Ethernet transceiver.
MPLS	MPLS is a widely supported method of speeding up data communication over combined IP/ATM networks.
Multimode Fibre	The most common type of fiber optic cabling used in network installations. Typically, multi-mode has a core diameter of 62.5 microns and an outer cladding diameter of 125 microns. Nearly all fiber based networking hardware (repeaters, switches, LAN cards etc.) are multi-mode.
NIC	Network Interface Card An adapter card providing the physical connection between a computer and the network medium.
Optical Fibre	Translucent fibre that can transmit beams of laser light. Ideal for reliable high speed LANs and backbones.
OSPF	Open Shortest Path First (OSPF) is a protocol used by routers on an IP network.
OTN	Open Transport Network
OXC	Optical Cross-Connects, connects optical networks providing versatility and is reconfigurable.
Photophone	A wireless communication device using light to transmit signals through air, patented by Alexander Graham Bell.
Router	A device that provides intelligent connections between networks. Routers operate at the network layer of the OSI model and are responsible for making decisions about which paths through a network the transmitted data will use.
SAS	Single stations, are attached to the ring concentrator and mainly inject and remove traffic from the primary ring.
SDH	Synchronous Digital Hierarchy, the international standard for transmitting digital information over optical networks.
Single-Mode Fibre	A type of fibre that uses a single path for light transmission (i.e. the light is not reflected within the core). Single-Mode fibre may support distances from between 2Km up to 20Km.
SONET	Synchronous Optical Network, an international standard for high-speed communication over fibre-optic networks.

Spanning-Tree Protocol	The Spanning-Tree Protocol is used to interconnect network switches.
Switch	A network device that selects a path or circuit for sending a unit of data to its next destination.
TCP	Transmission Control Protocol - A connection orientation transport protocol.
UDP	User Datagram Protocol - A connectionless orientated transport protocol. UDP is the transport protocol used by SNMP.
VLAN	Virtual LAN, a network of computers that behave as if they are connected to the same wire even though they may actually be physically located on different segments of a LAN.
WAN	Wide area network: a computer network that spans a wider area than does a local area network

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FIGURES

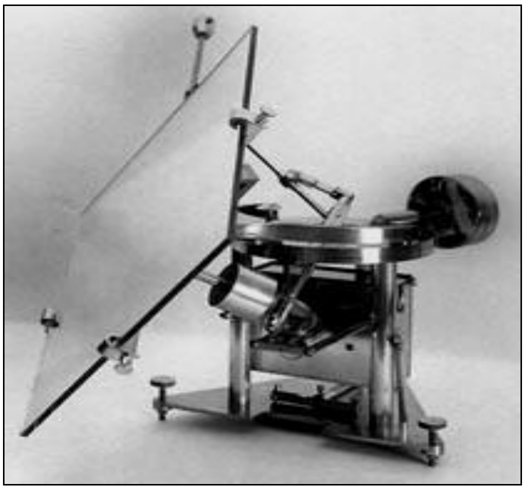

Fig 71.1 Alexander Graham Bell's Photophone

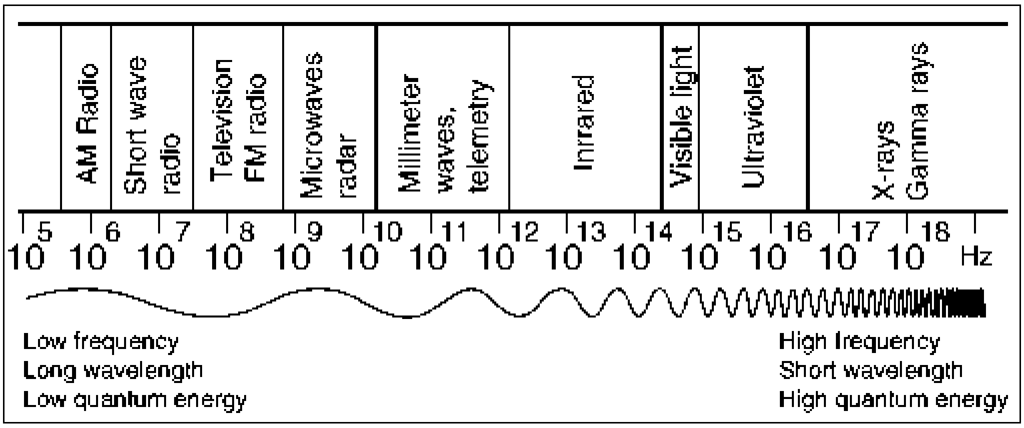

Fig 71.2 Electromagnetic Spectrum http://hyperphysics.phy-astr.gsu.edu/hbase/ems1.html

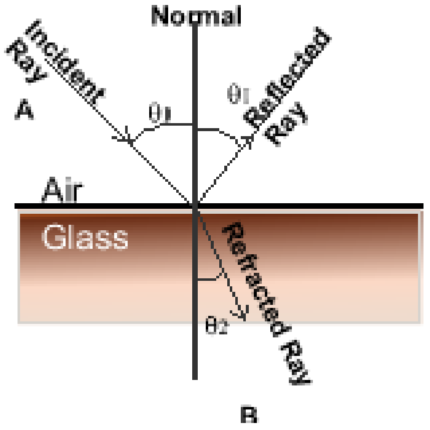

Fig 71.3 Reflection and Refraction

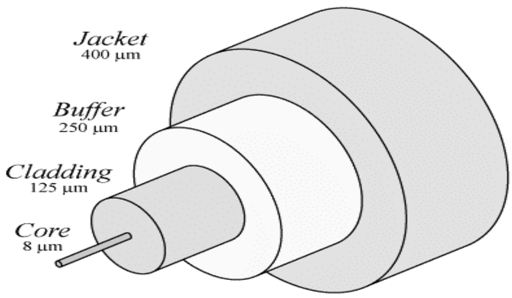

Fig 71.4: The structure of a fibre optic cable

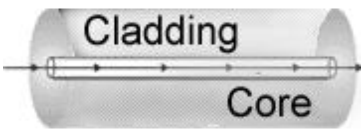

Fig 71.5: Single-mode Fibre

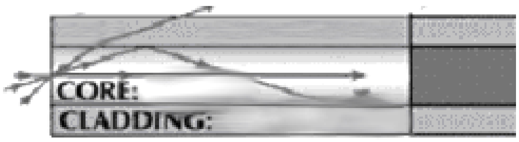

Fig 71.6 Total internal reflection in multimode step-index fibre

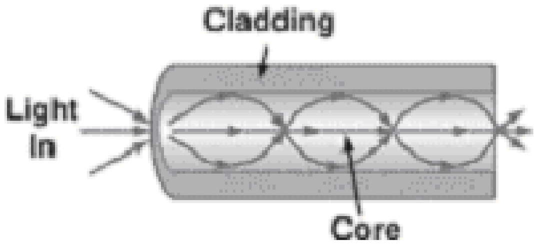

Fig 71.7: Multimode graded index fibre

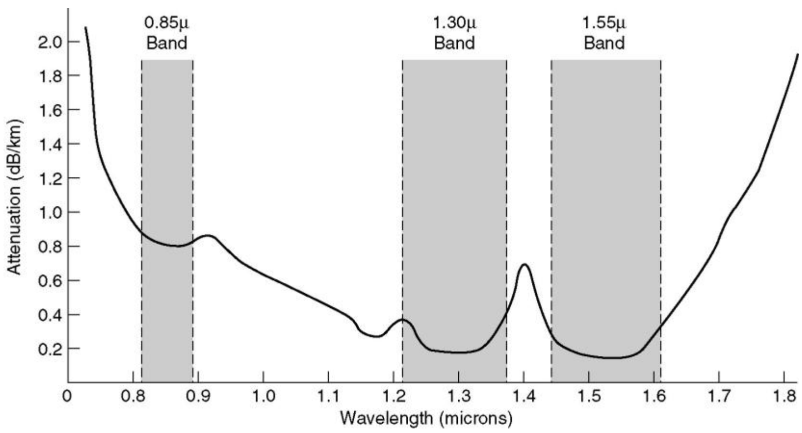

Fig 71.8: Attenuation (dB/Km) in a silica-based optical fibre

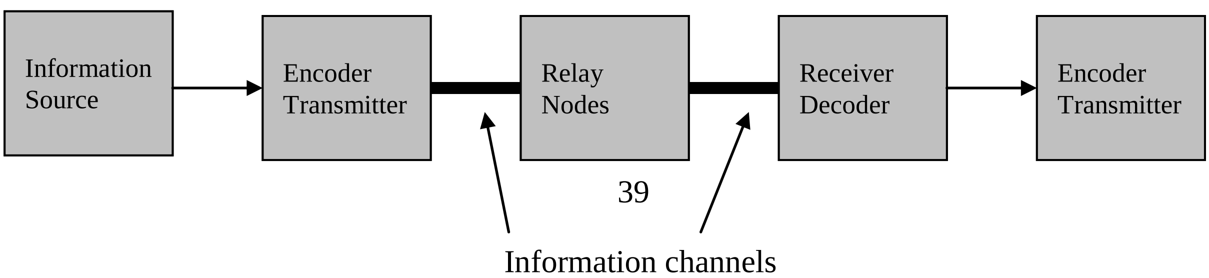

Fig 71.9: Components of a Fibre Optic Communication System

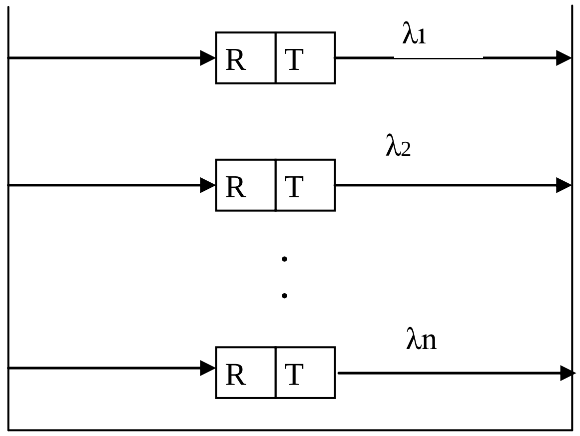

Fig 71.10: Optical LAN, Bus Topology

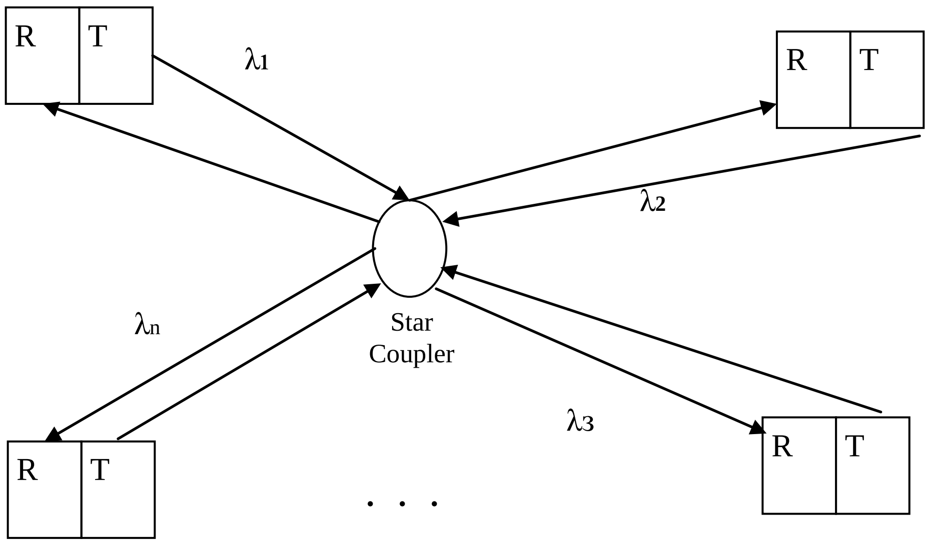

Fig 71.11: Optical LAN, Star Topology

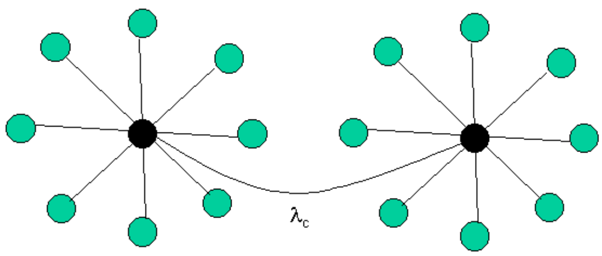

Fig 71.12: Interconnected Star Topologies

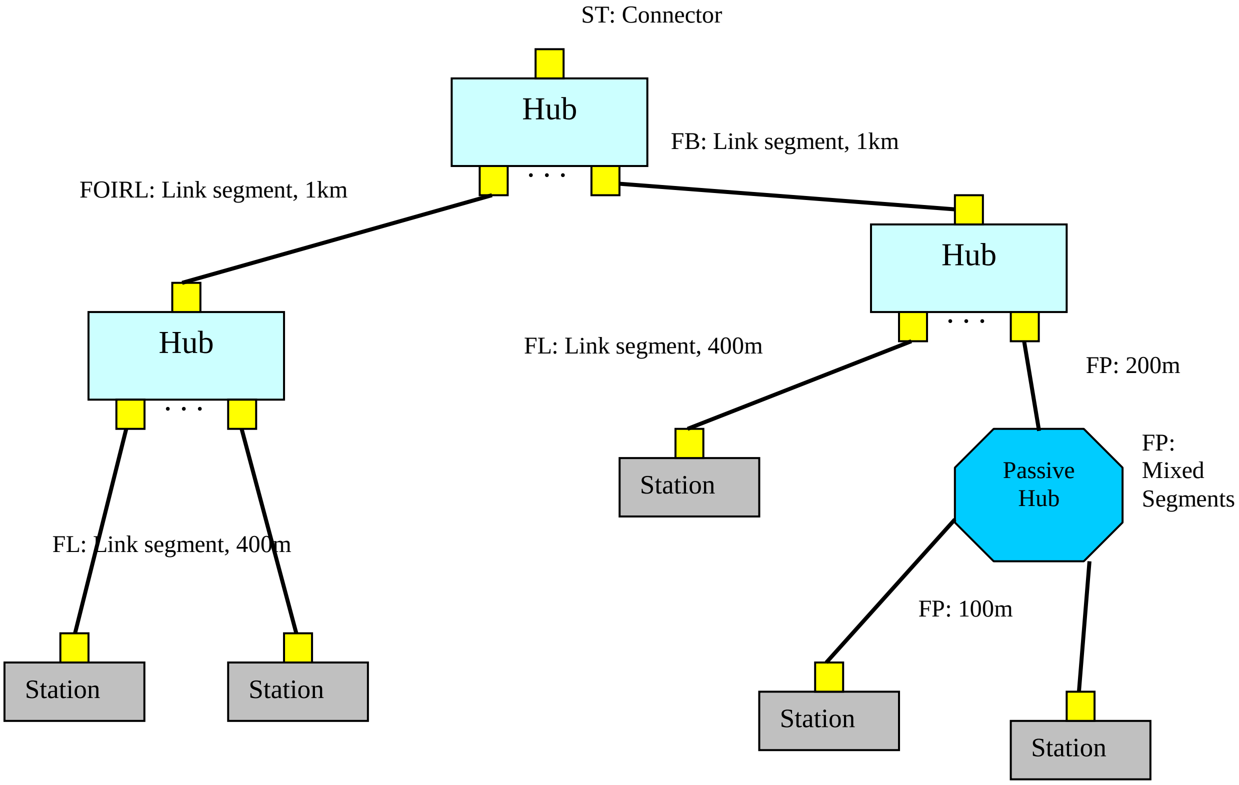

Fig 71.13: Mixed Optical LAN with 10BASE-F connections.

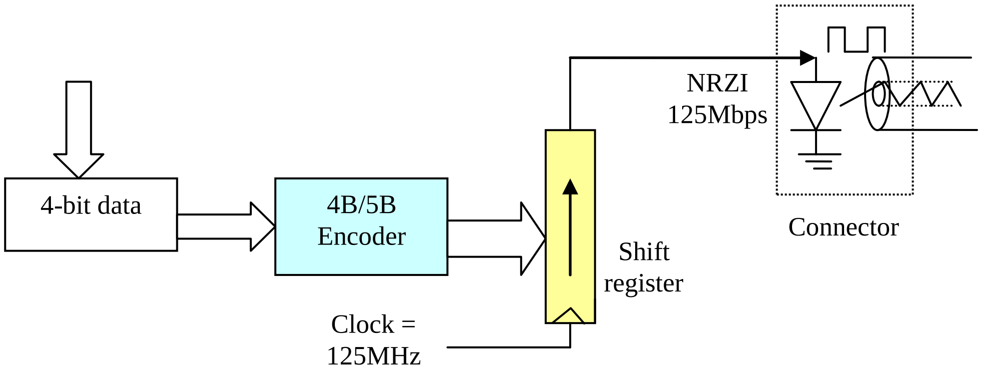

Fig 71.14: Encoding sequence for 100BASE-FX, which adopts the 4B/5B-encoding scheme

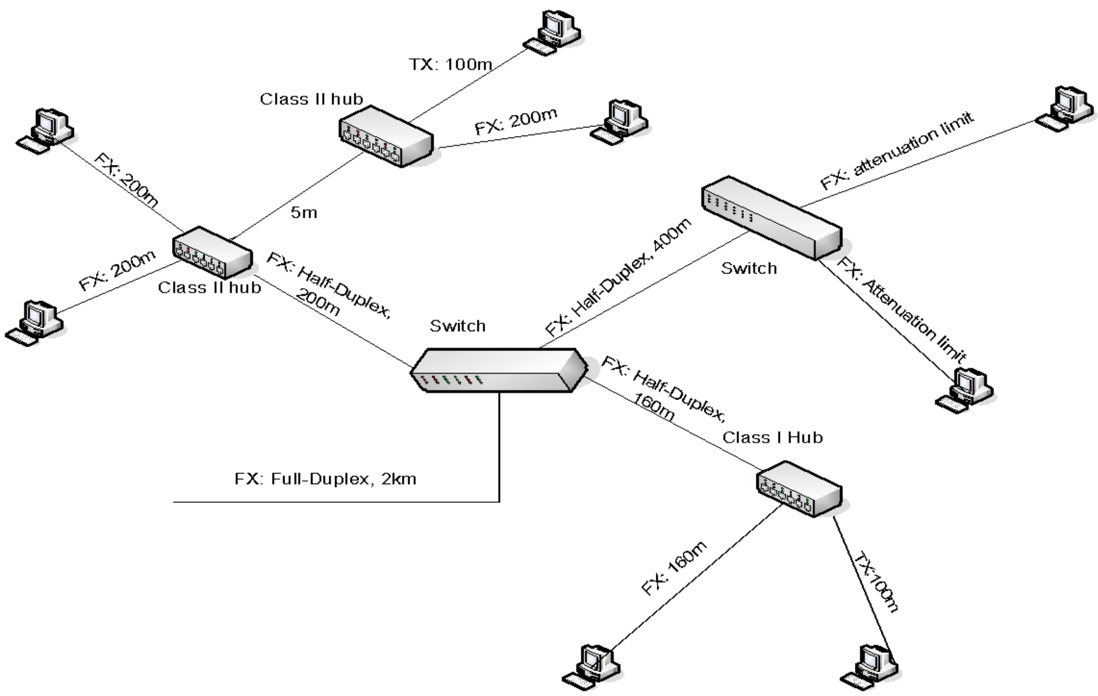

Fig 71.15: Mixed topology with 100BASE-FX length restrictions.

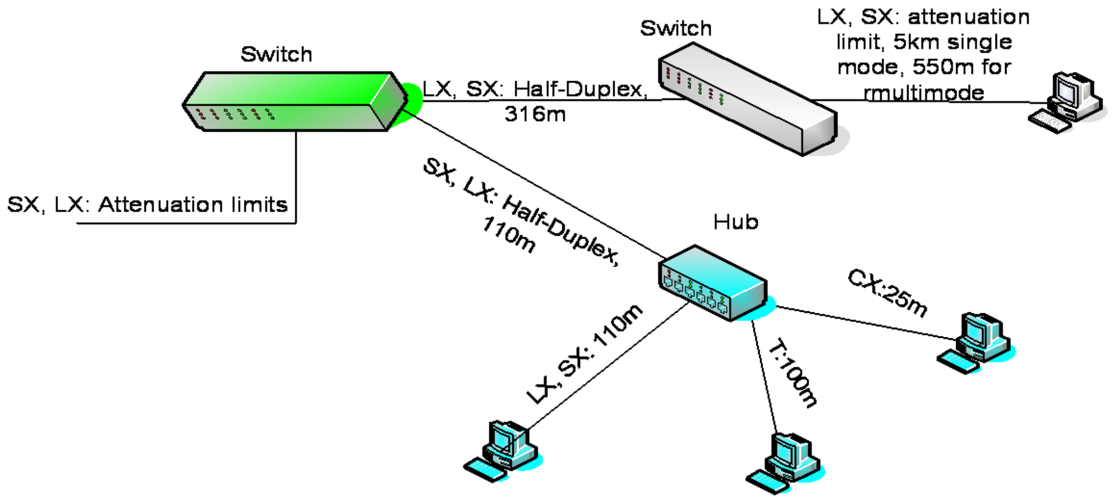

Fig 71.16: Mixture of 1000BASE cabling.

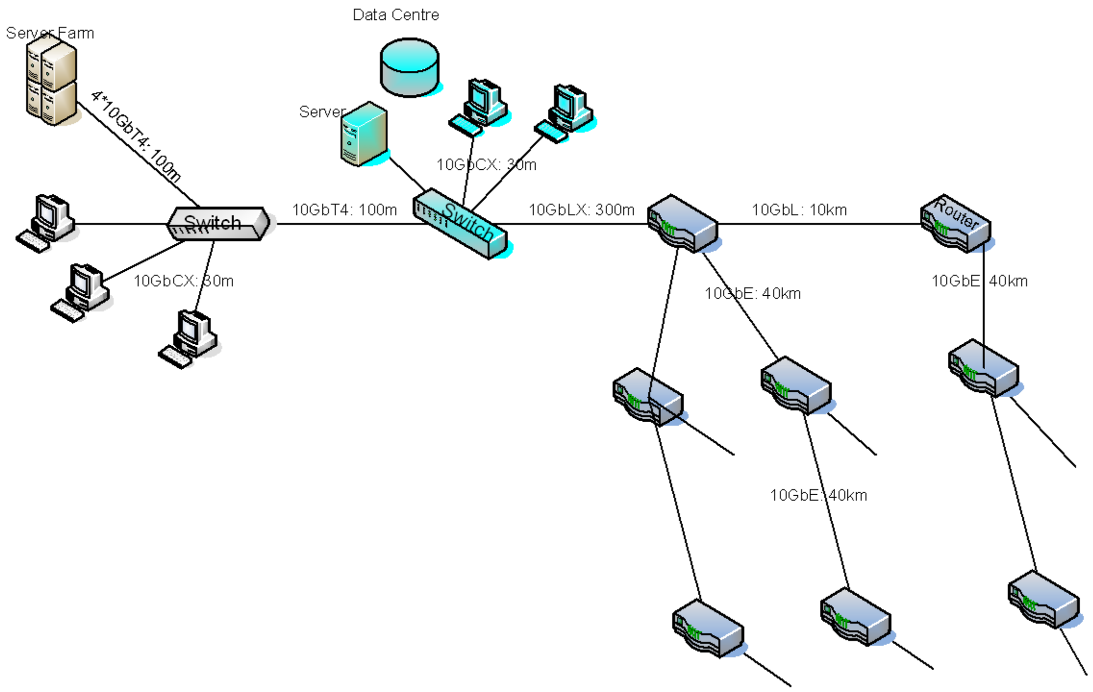

Fig 71.17: A network with mixed interconnections of all the 10GBASE classes

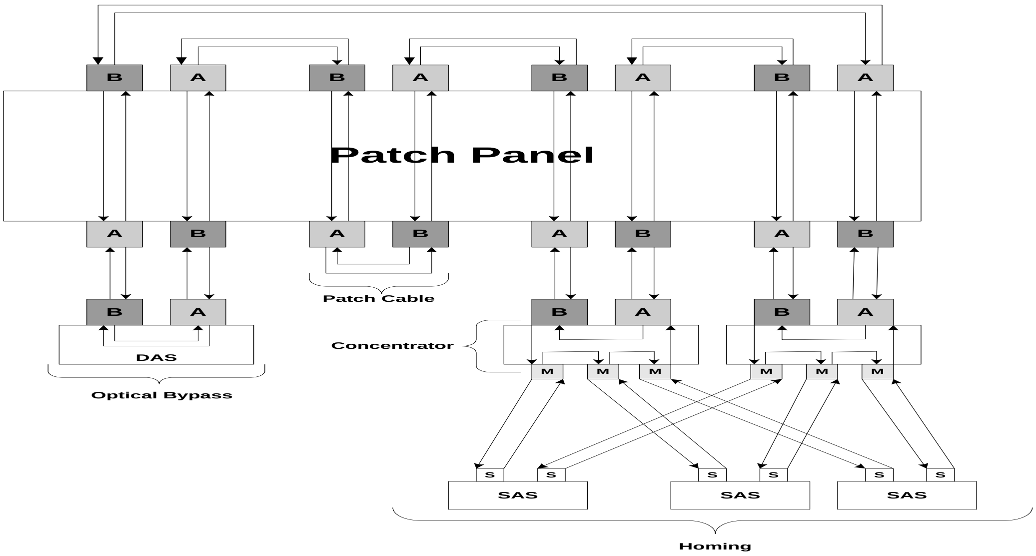

Fig 71.18: FDDI wiring connections, the connectors A, B, M and S are different types to provide proper connections to the ring.

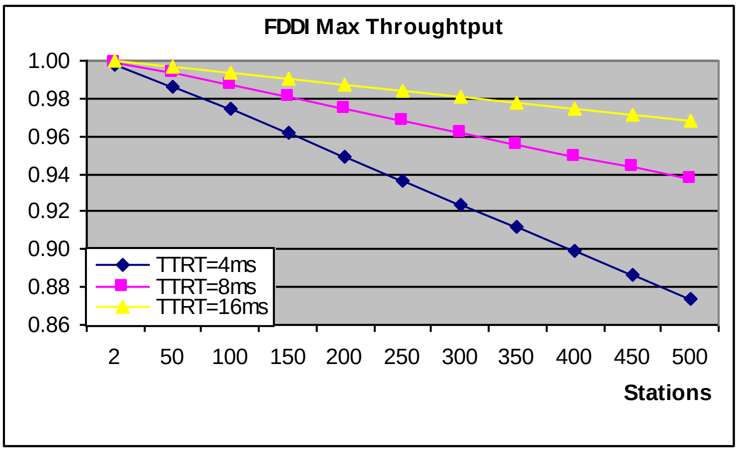

Fig 71.19: The maximum throughput attainable by he FDDI ring for a fibre of 500m as a function of the number of attached stations for various TTRT.

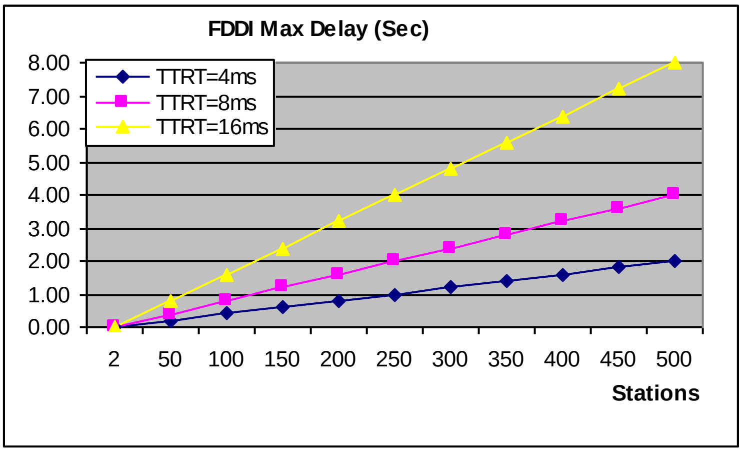

Fig 71.20: The maximum access delay attainable by he FDDI ring for a fibre of 500m as a function of the number of attached stations for various TTRT.

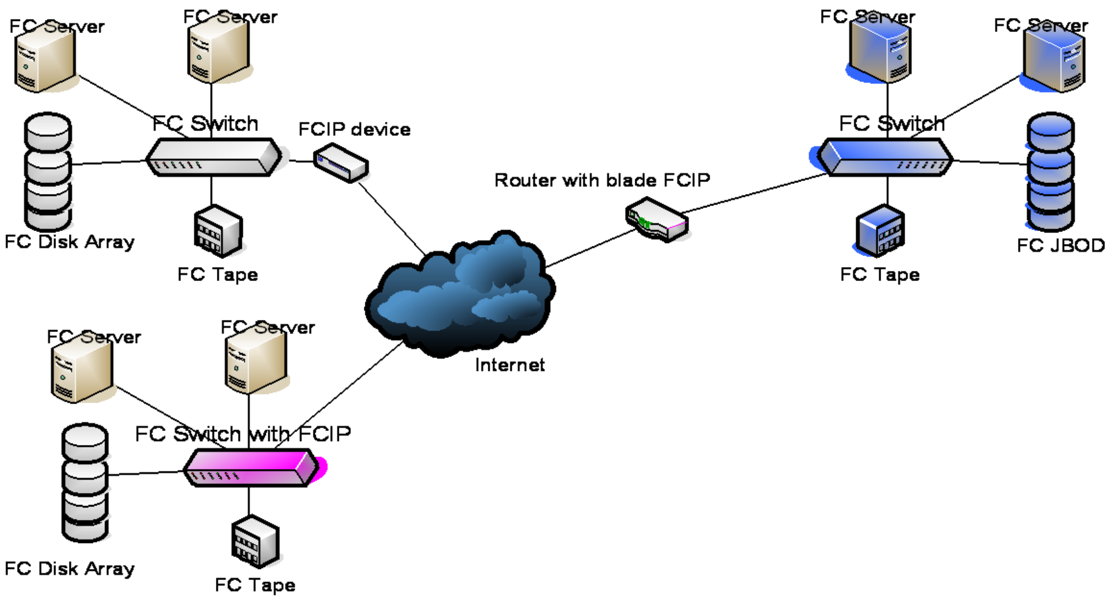

Fig 71.21: Three SANs connected through the Internet.

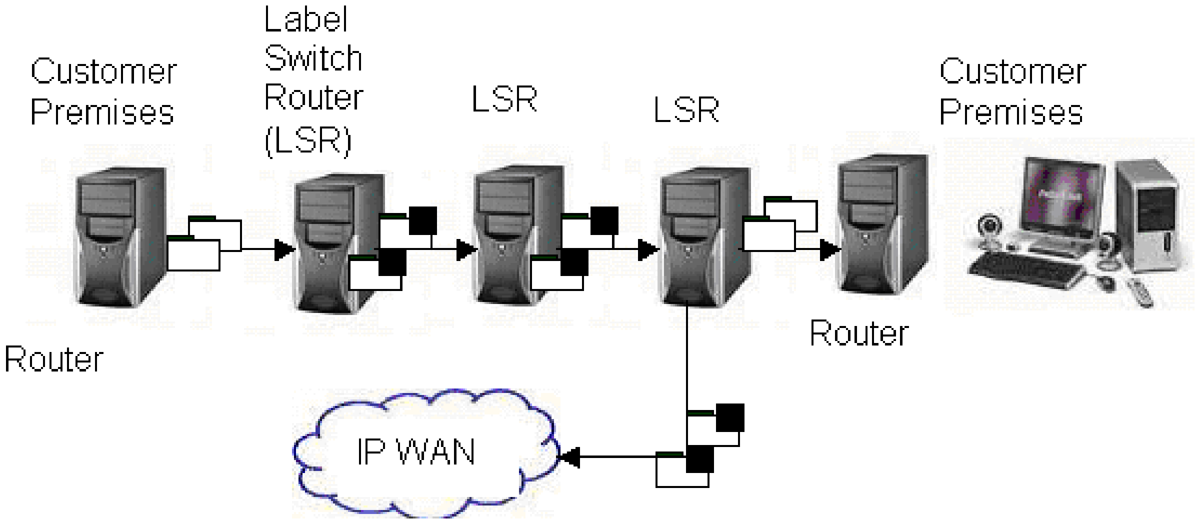

Fig 71.22: MultiProtocol Label Switching (MPLS)